Research of Survival-time-based Dynamic Adaptive Replica Allocation Algorithm in Mobile Ad Hoc Networks [1]

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Abstract. Power conservation and extending survival time are critical issues in mobile ad hoc networks, as the nodes are powered by battery only. In this paper, according to the mobility of nodes, the survival-time-based adaptive replica allocation algorithm is proposed. In the survival-time-based dynamic adaptive replica allocation algorithm, based on the locality of data access, the replica allocation scheme is adjusted regularly in order to reduce the power consumption, and thus extend the survival time of network. The relation between mobility models and efficiency of survival-time-based dynamic adaptive replica allocation algorithm is studied. The results of performance evaluation show that the survival-time-based dynamic adaptive replica allocation algorithm can reduce the total power consumption of network greatly and extend the survival time of network evidently.

1 Introduction

The mobile ad hoc networks [1] (MANET) consist of a collection of wireless nodes without a fixed infrastructure. In addition to the issues associated with a mobile network, the power consumption and mobility of the server(s) must also be considered in a MANET. While data replication is very effective for improving the data availability, mobile nodes generally have poor resources and it is impossible for mobile nodes to have replicas of all data items in the network.

At present, several algorithms are proposed for replica allocation in mobile ad hoc networks. Most of the existing algorithms are focused on the data availability during the network division, the power consumption of nodes is not considered sufficiently. The algorithms SAF[2], DAFN[3] and DCG[4] are proposed by Takahiro Hara in Osaka University. In these three algorithms, the access frequency from mobile nodes to each data item and the status of the network connection are taken into account to improve the data availability during the network division. The collection of global information

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of data access frequency will bring about vast communication cost, especially while the network topology changes frequently. The algorithm [5] proposed by Karen H. Wang in Toronto University, the algorithm [6] proposed by Jiun Long Huang in National Taiwan University and the algorithm [7] proposed by Kai Chen in Illinois University are all aimed at the group mobility model, and the replica allocation is decided by the prediction of network division.

In this paper, in view of the power consumption and survival time of nodes, a survival-time-based dynamic adaptive replica allocation algorithm (STDARA) is proposed. Section 2 states the problem and our motivation. Section 3 describes the survival-time-based dynamic adaptive replica allocation algorithm. Section 4 presents the results of performance evaluation. Section 5 provides a summary of our research work.

2 Model and Statement of the Problem

2.1 Power Control

Definition 1 Relay Region

The relay region of a node r for a node s is defined as

$$R(s,r)=\{x|P(s,r)+P(r,x)<P(s,x)\}.$$

$P(s,x)$ is the power incurred if node s directly transmits signal to node x, and $P(s,r)+P(r,x)$ is the power incurred if node s uses the node r as the relay node for transmission from s to node x.

Definition 2 Enclosure Region

The enclosure region of a node s is defined as

$$E(s)=\bigcap_{r\in T(s)}E(s,r).$$

The region $E(s,r)$ is called the enclosure region of node s by node r, it is the complement of region $R(s,r)$. $T(s)$ is the set of nodes lying within the transmission range of node s.

Definition 3 Neighbors

The neighbors of a node s is defined as

$$N(s)=\{y|y\in T(s),y\in E(s)\}.$$

The nodes that lie in the enclosure region of s is called the neighbors of s, and they are the only nodes to which s will maintain communication links for power-efficient transmission.

2.2 Data Access

Definition 4 Read-Write Pattern

The read-write pattern for an object O is the number of data access requests (read and write) to O generated by each node in a time interval t.

As the replica allocation is adjusted dynamically according to data access requests, the number of data access requests is weighted in view of the residual power of nodes.

Definition 5 Weighted Number of Read-Write Requests

The weighted number of read requests on object O received by u in the time interval t is

$$read_E(u) = \sum_{i \in N_{receive}(u)} \left(read(i) \times E_{\text{residual}}(i) / E_{init}(i) \right)$$

$read(i)$ is the number of read requests on object O generated by node i in the time interval t. $E_{init}(i)$ is the initial power of node i. $E_{\text{residual}}(i)$ is the residual power of node i. $N_{\text{receive}}(\text{u})$ is the set of nodes, from which the data access requests are transmitted to node u.

The weighted number of write requests on object O received by u in the time interval t is

$$write_E(u) = \sum_{i \in N_{receive}(u)} \left(write(i) \times E_{\text{residual}}(i) / E_{init}(i) \right)$$

$write(i)$ is the number of write requests on object O generated by node i in the time interval t.

2.3 Replica Allocation

Definition 6 Replica Allocation Scheme

The replica allocation scheme for an object O is the set of nodes at which O is replicated.

The power consumption of a single read request by node s is

$$P_{read}(s, O) = P(s, \ldots, r_v) = P(s, n_1) + \sum_{i=1}^{u-1} P(n_i, n_{i+1}) + P(n_u, r_v) .$$

r_v is the replica node of object O, which is chosen for read request. n_i (i = 1, 2, …, u) is the relay nodes between s and r_v.

The power consumption of a single write request by node s is

$$P_{write}(s, O) = P(s, \ldots, r_v) + \sum_{r_i \in r\_set(O)} P(r_v, \ldots, r_i) .$$

$r\_set(O)$ is the set of replica nodes of object O. $P(s,\ldots,r_v)$ is the power consumption of update operation on r_v, $\sum_{r_i \in r\_set(O)} P(r_v,\ldots,r_i)$ is the power consumption of update operations on other replica nodes in $r\_set(O)$.

The total power consumption of data access to object O in a time interval t is

$$POWER(O) = \sum_{s \in N} \left(\mathrm{Re}\,ad(s,O) \times P_{read}(s,O) + Write(s,O) \times P_{write}(s,O) \right).$$

$\mathrm{Re}\,ad(s,O)$ is the number of read requests to O in a time interval t, $Write(s,O)$ is the number of write requests to O in a time interval t.

The problem of finding an optimal replica allocation scheme has been proved to be NP-complete for different power consumption models. In this paper, based on the heuristic algorithm, a survival-time-based dynamic adaptive replica allocation algorithm is proposed to find a suboptimal replica allocation scheme.

3 Replica Allocation Considering Survival Time

STDARA is executed periodically and independently in each replica node, the execution cycle is set according to the change of network topology and read-write pattern.

STDARA includes expansion test, switch test and contraction test. The description of STDARA is as follows:

```
//for object O, m∈ r_set(O)
Calculate the neighbors of replica node rn, which is
denoted as N(rn).
for ( u∈N(m) , u∉r_set(O) )
{ // expansion test is done for each neighbor of m,
which is not replica node of object O
      if ( the expansion condition is satisfied )
      { // replica expansion
             r_set(O) = r_set(O) + {u} ;
             return;
      }
}
for ( u∈N(m) , u∉r_set(O) )
{ // expansion test is done for each neighbor of m,
which is not replica node of object O
      if ( the switch condition is satisfied )
      { // replica switch
             r_set(O) = r_set(O) - {m} + {u} ;
             return;
      }
}
for ( m )
{ // contraction test is done for m
      if ( the contraction condition is satisfied )
```

```
        { // replica contraction
              r_set(O) = r_set(O) - {m};
              return;
        }
  }
```

There are two extreme situations for expansion test (Fig.1).

In Fig.1(a), each shortest path between u and replicas of object O will pass through m. In Fig.1(b), each shortest path between m and other replicas of object O will pass through u. The compromised expansion condition is as follows:

$$\Delta E = \sum_{r \in r\_set(O)} write_E(r) \times P(r,\ldots,u) - (read_E(u) + write_E(u)) \times P(u,m) < 0 \quad \textbf{(1)}$$

$write_E(r)$ is the weighted number of write requests on object O received by r in the time interval t, $read_E(u)$ is the weighted number of read requests on object O received by u in the time interval t.

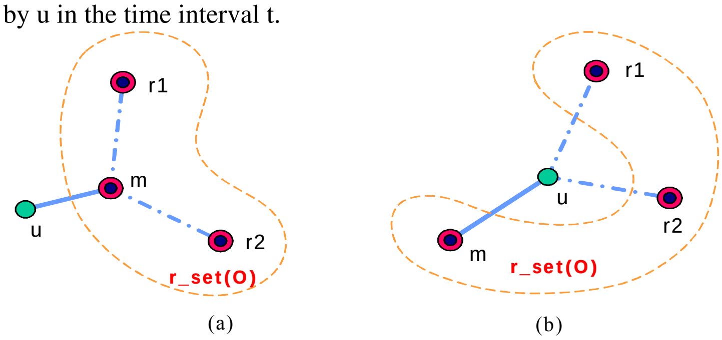

Fig. 1. Two extreme situations for expansion test and switch test

There are two extreme situations for switch test (Fig.1).

In Fig.1(a), each shortest path between u and replicas of object O will pass through m. In Fig.1(b), each shortest path between m and other replicas of object O will pass through u. The compromised switch condition is as follows:

$$\Delta E = (read_E(m) + write_E(m)) \times P(u,m) - (2 \times write_E(u) + read_E(u)) \times P(u,m) < 0 \quad \textbf{(2)}$$

There are two extreme situations for contraction test (Fig.2).

In Fig.2(a), each shortest path between u and other replicas of object O will pass through m. In Fig.2(b), each shortest path between m and other replicas of object O will pass through u. The compromised contraction condition is as follows:

$$\Delta E = (read_E(u) + write_E(u)) \times P(u,m) - \sum_{r \in r\_set(O)} write_E(r) \times P(r,\ldots,u) < 0 \quad \textbf{(3)}$$

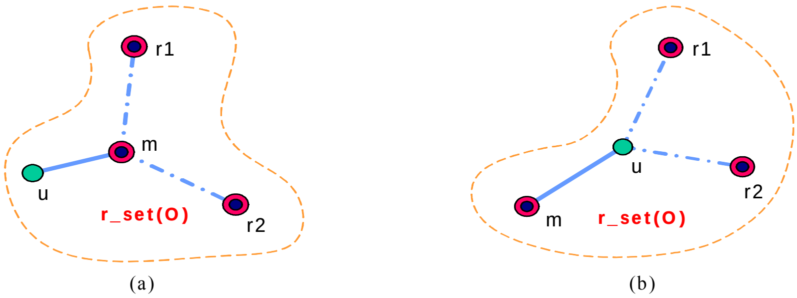

Fig. 2. Two extreme situations for contraction test

4 Performance Evaluation

4.1 Influence of Mobility of Nodes on Efficiency of Survival-time-based Dynamic Adaptive Replica Allocation Algorithm

The parameters of test environment are shown in Table 1. We compare STDARA and algorithm ADR-G [8]. In ADR-G, the spanning tree is build to organize replicas. The mobility model of nodes is Random Waypoint Mobility Model [9].

Table 1. Parameters of test environment

parameter	default value
range of movement	1000m×1000m
number of mobile nodes	50
speed of migration	0m/s ~ 10m/s
direction of migration	$0 \sim 2\pi$
number of objects	1
interval of algorithm execution	10s
initial number of replica	5
ratio between reads and writes	5:1
initial node power	10×10^{3} J
power consumption model	two-ray ground reflection Model (n=4)
antenna	Omni-directional Antenna

In Fig.3, the total mobile node power decreased gradually. Compared with ADR_G, the mean power consumption in STDARA is 35.7% less. In STDARA, the replica allocation scheme is adjusted according to power consumption, so the power consumption is reduced greatly, and the survival time of network is extended evidently.

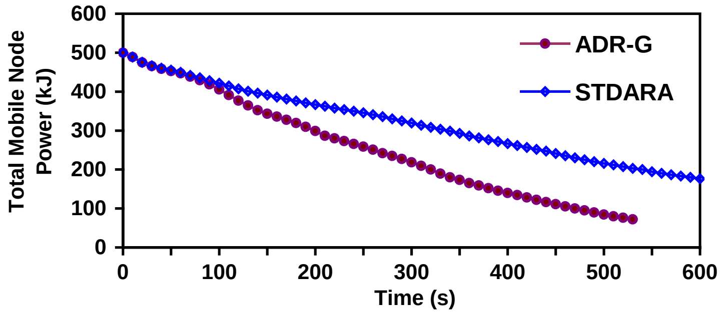

Fig. 3. Mobility of nodes

4.2 Relation Between Mobility Models and Efficiency of Survival-time-based Dynamic Adaptive Replica Allocation Algorithm

Three typical mobility models [9] are selected to investigate the relation between mobility models and efficiency of STDARA. Three mobility models are Random Waypoint Mobility Model, Random Gauss-Markov Mobility Model and Reference Point Group Mobility Model, which are denoted as RW, GM and RPG respectively. The parameters of test environment are shown in Table 1. We observe the influence of different mobility models with different speed of migration on efficiency of STDARA.

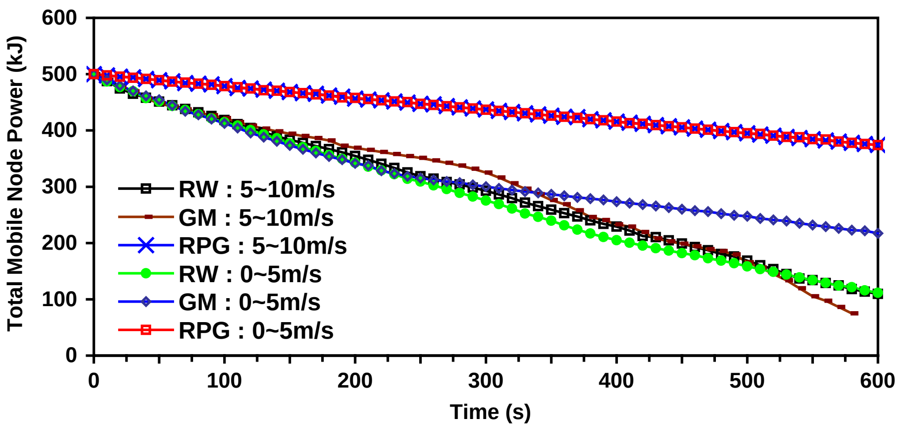

Fig. 4. Mobility models

In Random Waypoint Mobility Model (Fig.4), the power consumption difference between different speeds of migration is little. In Random Gauss-Markov Mobility Model (Fig.4), the speed of migration influences the power consumption obviously.

The speed of migration is higher, network topology changed more frequently, if the replica allocation scheme is not adjusted in time, the power consumption will be increased more greatly. In Reference Point Group Mobility Model (Fig.4), only one group is selected, the relative movement between nodes is little, the network topology is relatively stable, thus the replica allocation scheme can be adjusted in time, so the power consumption will not increased greatly.

5 Conclusion

The power consumption and mobility of nodes are significant characteristic of mobile ad hoc network. In the survival-time-based dynamic adaptive replica allocation algorithm, according to the power consumption of nodes, the replica allocation scheme is adjusted regularly, the replicas are distributed evenly among all the nodes, thus extend the survival time of network. The results of performance evaluation show that the survival-time-based dynamic adaptive replica allocation algorithm can reduce the total power consumption of network greatly and extend the survival time of network evidently. The relation between mobility models and efficiency of survival-time-based dynamic adaptive replica allocation algorithm is studied

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